Chapter 1
Introduction

1-1. Purpose

This engineer manual (EM) describes the inspection, evaluation, and repair of hydraulic steel structures, including preinspection identification of critical locations (such as fracture critical members and various connections) that require close examination. Nondestructive testing techniques that may be used during periodic inspections or detailed structural inspections are discussed. Guidance is provided on material testing to determine the chemistry, strength, ductility, hardness, and toughness of the base and weld metal. Analyses methods that can be used to determine structure safety, safe inspection intervals, and expected remaining life of the structure with given operational demands are presented. Finally, considerations for various types of repair are discussed.

1-2. Applicability

This manual applies to all USACE commands having responsibilities for the design of civil works projects.

1-3. Distribution

This publication is approved for public release; distribution is unlimited.

1-4. References

Required and related publications are provided in Appendix A.

1-5. Background

a. *Structural evaluation.* USACE currently operates over 150 lock and dam structures that include various hydraulic steel structures, many of which are near or have reached their design life. Structural inspection and evaluation are required to assure that adequate strength and serviceability are maintained at all sections as long as the structure is in service. Engineer Regulation (ER) 1110-2-100 prescribes general periodic inspection requirements for completed civil works structures, and ER 1110-2-8157 provides specific requirements for hydraulic steel structures. Neither provides specific guidance for structural evaluation. To conduct a detailed inspection for all hydraulic steel structures is not economical, and detailed inspection must be limited to critical areas. When inspections reveal conditions that compromise the safety or serviceability of a structure, a structural evaluation must be conducted; and depending on the results, repair may be necessary. This EM provides specific guidance on inspection focused on critical areas, structural evaluation with emphasis on fatigue and fracture, and repair procedures. Fatigue and fracture concepts are emphasized because it is evident that steel fatigue and fracture are real problems. Many existing hydraulic steel structures in several USACE projects have exhibited fatigue and fracture failures, and many others may be susceptible to fatigue and fracture problems (see *c* below and Chapter 8).

b. *Types of hydraulic steel structures*. Lock gates are moveable gates that provide a damming surface across a lock chamber. Most existing lock gates are miter gates and vertical-lift gates, with a small percentage being sector gates and submergible tainter gates. Spillway gates are installed on the top of dam spillways to provide a moveable damming surface allowing the spillway crest to be located below a given operating water level. Such gates are used at locks and dams (navigation projects) and at reservoirs (flood control or hydropower projects). Spillway gates are generally tainter gates, the most common, or lift gates, but some projects use roller gates. Other types of hydraulic steel structures include bulkheads, needle beams, lock culvert valves, and stop logs.

(1) Spillway tainter gates. A tainter gate is a segment of a cylinder mounted on radial arms, or struts, that rotate on trunnions anchored to the dam piers. Numerous types of framing exist; however, the most common type of gate includes two or three frames, each of which consists of a horizontal girder that is supported at each end by a strut. Each frame lies in a radial plane with the struts joining at the trunnion. The girder supports the stiffened skin plate assembly that forms the damming surface. Spillway flow is regulated by raising or lowering the gate to adjust the discharge under the gate.

(2) Miter gates. The majority of lock gates are miter gates, primarily because they tend to be more economical to construct and operate and can be opened and closed more rapidly than other types of lock gates. Miter gates are categorized by their framing mechanism as either vertically or horizontally framed. On a vertically framed gate, water pressure from the skin plate is resisted by vertical beam members that are supported at the ends by a horizontal girder at the top and one at the bottom of the leaf. The horizontal girders transmit the loads to the miter and quoin at the top of the leaf and into the sill at the bottom of the leaf. Horizontally framed lock gates include horizontal girders that resist the water loads and transfer the load to the quoin block and into the walls of the lock monolith. Current design guidance as provided by EM 1110-2-2703 recommends that future miter gates be horizontally framed; however, a large percentage of existing miter gates are vertically framed.

(3) Sector gates. Another type of lock gate is the sector gate. This gate is framed similar to a tainter gate, but it pivots about a vertical axis as does a miter gate. Sector gates have traditionally been used in tidal reaches of rivers or canals where the dam may be subject to head reversal. Sector gates may be used to control flow in the lock chamber during normal operation or restrict flow during emergency operation. Sector gates are generally limited to lifts of 3 m (10 ft) or less.

(4) Vertical lift gates. Vertical lift gates have been used as lock gates and spillway gates. These gates are raised and lowered vertically to open or close a lock chamber or spillway bay. They are essentially a stiffened plate structure that transmits the water load acting on the skin plate along horizontal girders into the walls of the lock monolith or spillway pier. Lift gates can be operated under moderate heads, but not under reverse head conditions. Specific design guidance for lift gates is specified by EM 1110-2-2701.

(5) Submergible tainter gates. Submergible tainter gates are used infrequently as lock gates. This type of gate pivots similar to a spillway tainter gate but is raised to close the lock chamber, and is lowered into the chamber floor to open it. The load developed by water pressure acting on skin plate is transmitted along horizontal girders to struts that are recessed in the lock wall. The struts are connected to and rotate about trunnions that are anchored to each lock wall.

(6) Bulkheads, stop logs, needle beams, and tainter valves.

(a) Bulkheads are moveable structures that provide temporary damming surfaces to enable the dewatering of a lock chamber or gate bay between dam piers. Slots are generally provided in the sides of lock chambers or piers to provide support for the bulkhead.

(b) Stop logs are smaller beam or girder structures that span the desired opening and are stacked to a desired damming height. A number of stacked stop logs make up a bulkhead.

(c) A needle dam consists of a sill, piers, a horizontal support girder that spans between piers, and a series of beams placed vertically between the sill and horizontal support girder. The vertical beams are referred to as needle beams. These are placed adjacent to each other to provide the damming surface.

(d) Tainter valves are used to regulate flow through lock chambers. Tainter valves are geometrically similar to tainter gates; however, the valves are generally oriented such that their struts are in tension as opposed to spillway gates that resist load with their struts in compression.

c. Examples of distressed hydraulic steel structures. The following brief examples, all taken from a single District, illustrate the potential results of casual inspection combined with inattention to fatigue and fracture concepts during design. These examples represent only a few of the steel cracking problems that have occurred on USACE projects. Chapter 8 provides other examples with recommended repair procedures.

(1) Miter gate anchorage.

(a) This case involves a failure on a downstream, vertically framed miter gate that spanned a 33.5-m- (110-ft-) wide lock. The upper embedded gate anchorage failed unexpectedly while the chamber was at tail-water elevation. Failure occurred by fracture at the gudgeon pin hole. The anchor was a structural steel assembly composed of two channels and two 12-mm- (1/2-in.-) thick plates. The use of a channel with upturned legs resulted in ponding of water that caused pitting and scaling corrosion of the channel. Since the anchor is a nonredundant tension member, failure caused the leaf to fall to the concrete sill, though it remained vertical.

(b) The failure surfaces were disposed of without an examination to determine the cause of failure. To make the lock operational as quickly as possible, repairs were implemented without any evaluation or recommendations from the District's Engineering Division. These repairs consisted of butting and welding a new channel section to the remaining embedded section and bolting a 25-mm (1-in.) cover plate to the channel webs. The bolt and plate materials are not known.

(c) The same type of anchorage is used on at least two other projects with a total of 16 similar anchors.

(2) Spare miter gate.

(a) The project had a spare miter gate consisting of five welded modules stacked and bolted together. The spare gate had been used several times. One month after the last installation, cracks were discovered in the downstream flanges of three vertical girders. The cracks originated at the downstream face of the flange in the heat-affected zone at the toe of a transverse fillet weld. (This detail has low fatigue strength.) The cracks then propagated through the flange and into the web. After cracking, the downstream face of the flange was 12.5 mm (0.5 in.) out of vertical alignment.

(b) Quick repairs were performed by operations personnel, without input from engineering personnel. The web crack was filled with weld metal. The flange cracks were gouged and welded, and two small bars were fillet welded across the crack. The bar material is unknown. These repairs served to get the gate back into service immediately. However, reliable long-term repairs should be developed and implemented. This example is further discussed in paragraph 8-6*b*.

(3) Submersible lift gate.

(a) This project includes a submersible lift gate as the primary upstream lock gate. The gate consists of two leaves with six horizontal girders spanning 33.5 m (110 ft). Several cracks were discovered in one leaf while the lock was out of service for other repairs. Subsequent detailed inspection identified over 100 cracks in girder flanges and bracing members. One crack extended through the downstream flange of a horizontal girder and 1 m (3 ft) into the 2.5-m- (8-ft-) deep web.

(b) This gate was subjected to a detailed investigation to determine the cause of the cracking. The study identified several contributing factors: the original design had ignored a loading case and had included improper loading assumptions; limit switches were improperly stopping the gate before it reached its supports; the design ignored higher stresses caused by eccentric connections on the downstream face; most of the original welds did not meet current American Welding Society (AWS) quality standards; the steel for the gate had a low fracture toughness, ranging from 6.8 J (5 ft-lb) at 0 ^{o}C (32 ^{o}F) to 20 J (15 ft-lb) at 21 ^{o}C (70 ^{o}F).

(c) Repair procedures were designed by engineering personnel for this gate. However, the specified weld procedures were not used by the contractor, and the welders were not properly qualified per AWS requirements. These factors may have caused inadequate repair welds, which duplicates part of the causes of the original cracking problem. This example is further discussed in paragraph 8-6*c*.

1-6. Mandatory Requirements

This manual provides guidance for the protection of USACE structures. In certain cases, guidance requirements are considered mandatory because they are critical to project safety and performance as discussed in ER 1110-2-1150. Structural inspection and evaluation (and repair if necessary) are critical. These are best carried out on a case-by-case basis, however, and general mandatory requirements are not provided. In the inspection, evaluation, and repair process, guidance contained herein should be used where appropriate.